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<b>UTILITY PATENT APPLICATION TRANSMITTAL</b>  For new nonprovisional applications under 37 CFR 1.53(b)	Attorney Docket No.	GEH-01-060	
	First Named Inventor or Application Identifier		Charles L. Zahm
	Title		METHODS AND APPARATUS FOR MEASURING NAVIGATIONAL PARAMETERS OF A LOCOMOTIVE
	Express Mail Label No.		EL319729735US

APPLICATION ELEMENTS See MPEP chapter 600 concerning utility patent application contents.		ADDRESS TO: Assistant Commissioner for Patents Box Patent Application Washington, DC 20231	
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2. <input checked="" type="checkbox"/> Specification (Preferred arrangement set forth below) [Total Pages] <b>16</b> - Descriptive title of the Invention - Cross References to Related Applications - Statement Regarding Fed sponsored R & D - Reference to Microfiche Appendix - Background of the Invention - Brief Summary of the Invention - Brief Description of the Drawings (if filed) - Detailed Description - Claim(s) - Abstract of the Disclosure		7. Nucleotide and/or Amino Acid Sequence Submission (If applicable, all necessary) a. <input type="checkbox"/> Computer Readable Copy b. <input type="checkbox"/> Paper Copy (identical to computer copy) c. <input type="checkbox"/> Statement verifying identity of above copies	
3. <input checked="" type="checkbox"/> Drawing(s) (35 USC 113) [Total Sheets] <b>5</b>		<b>ACCOMPANYING APPLICATION PARTS</b>	
4. Oath or Declaration [Total Pages] <b>4</b> a. <input checked="" type="checkbox"/> Newly executed (original or copy) b. <input type="checkbox"/> Copy from a prior application (37 CFR 1.63(d)) (for continuation/divisional with Box 17 completed) [Note Box 5 below] i. <input type="checkbox"/> <b>DELETION OF INVENTOR(S)</b> Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b). <input type="checkbox"/> Incorporation by Reference (useable if Box 4b is checked) The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied under Box 4b, is considered as being part of the disclosure of the accompanying application and is hereby incorporated by reference therein.		8. <input checked="" type="checkbox"/> Assignment Papers (cover sheet & document(s)) 9. <input type="checkbox"/> 37 CFR 3.73(b) Statement <input checked="" type="checkbox"/> Power of Attorney (when there is an assignee) 10. <input type="checkbox"/> English Translation Document (if applicable) 11. <input type="checkbox"/> Information Disclosure Statement (IDS)/PTO-1449 <input type="checkbox"/> Copies of IDS Citations 12. <input type="checkbox"/> Preliminary Amendment 13. <input checked="" type="checkbox"/> Return Receipt Postcard (MPEP 503) (Should be specifically itemized) 14. <input type="checkbox"/> Small Entity Statement(s) <input type="checkbox"/> Statement filed in prior application, Status still proper and desired (PTO/SB/09-12) 15. <input type="checkbox"/> Certified Copy of Priority Document(s) (If foreign priority is claimed) 16. <input checked="" type="checkbox"/> Other: <b>Certificate of Express Mailing</b>	
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NAME	John S. Beulick Armstrong Teasdale LLP				
ADDRESS	Suite 2600 One Metropolitan Square				
CITY	St. Louis	STATE	MO	ZIP CODE	63102-2740
COUNTRY	U.S.A	TELEPHONE	(314) 621-5070	FAX	(314) 621-5065

Name (Print/type)	Patrick W. Rasche	Registration No. (Attorney/Agent)	37,916
Signature	<i>Patrick W. Rasche</i>	Date	6/1/00

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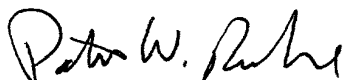
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I certify that the attached utility patent application claiming benefit of Provisional Application Serial No. 60/153,304 filed September 10, 1999 of **CHARLES L. ZAHM, WILLIAM L. MATHESON and KEVIN M. CLYNE**, for **METHODS AND APPARATUS FOR MEASURING NAVIGATIONAL PARAMETERS OF A LOCOMOTIVE**, including:

- Patent Application Transmittal (1 pg, in duplicate)
- Fee Transmittal (in duplicate) (1 page)
- Nine (9) pages of specification; six (6) pages of claims; one (1) page of abstract
- Five (5) sheets of drawings
- Declaration and Power of Attorney of Charles L. Zahm and William L. Matheson (2 pages)
- Declaration and Power of Attorney of Kevin M. Clyne (2 pages)
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Patrick W. Rasche  
Reg. No. 37,916  
Armstrong Teasdale LLP  
One Metropolitan Square, Suite 2600  
St. Louis, MO 63102

GEH-01-060

METHODS AND APPARATUS FOR MEASURING  
NAVIGATIONAL PARAMETERS OF A  
LOCOMOTIVE

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 60/153,304, filed September 10, 1999, which is hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

5 This invention relates generally to methods and apparatus for measuring navigation parameters of a locomotive, and more specifically to methods of determining movement and direction of a track-bound transportation apparatus using GPS satellites.

10 Modern algorithms for train navigation incorporate very sensitive turn rate gyroscopes (gyros) that permit detection of low speed through high number turnouts such as a #20 equilateral turnout. These gyroscopes are quite expensive, and suffer from coning problems due to superelevation. In addition, measurement drift accumulates over time. This drift must be corrected periodically by reference to data in a track data base. It would therefore be desirable to replace gyroscopes (gyros) in  
15 such applications altogether or to provide an alternate system for determining heading accurately for low speed and high speed turnouts. Where trains move over a curving track, the rails wear down due to friction between the wheels of the train and the rails. As used herein, a curve is represented by any change in path direction. Therefore, curving means that a path direction is changing. One solution to this problem is to provide lubricant to the rails or to the wheels when a train is moving. However, this  
20 solution is wasteful of lubricant. It would therefore be desirable to provide a method and apparatus to more efficiently reduce rail wear on curving tracks by determining when a train is on a curve and by applying lubricant.

## BRIEF SUMMARY OF THE INVENTION

There is therefore provided, in one embodiment, a method for determining motion and/or location parameters of a locomotive. This method embodiment includes steps of phase locking a pair of receivers having antennas at different locations on a locomotive to reference signals received from a set of at least three satellites, determining a set of phase differences between the reference signals received at the antennas, and determining at least one of an accurate heading, and/or heading rate of the locomotive using the set of phase differences between the reference signals.

The above embodiment can be implemented on a train using inexpensive satellite receivers and an inexpensive processor, and can be used in conjunction with a gyroscope having reduced specifications to provide accurate heading information in both low and high speed turnouts. In addition, the heading information provided by this embodiment can advantageously be used to reduce usage of lubricants applied to reduce track wear.

## BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a drawing of a locomotive showing a relative location of receiving antennas of one embodiment of the present invention installed thereon;

Figure 2 is a diagram of an embodiment of a heading and attitude system of the present invention;

Figure 3 is a top view of a locomotive on a curving track;

Figure 4 is a drawing of a locomotive engine showing an embodiment of a lubricant dispenser applying a lubricant to track rails;

Figure 5 is a block diagram of an embodiment of a rail lubricant control system of the present invention employing a gyroscope and a tachometer;

Figure 6 is a block diagram of an embodiment of a rail lubricant control system of the present invention employing two GPS satellite receivers and a tachometer; and

5 Figure 7 is a block diagram of an embodiment of a rail lubricant control system of the present invention employing a lateral accelerometer and a tachometer.

## DETAILED DESCRIPTION OF THE INVENTION

10 In one embodiment and referring to Figure 1, inexpensive carrier phase satellite, for example Global Positioning Satellite (GPS), receivers are used to determine train heading very accurately for low and high speed turnouts, which may be used in locomotive nav-systems.

15 Two antennas 10, 12 are mounted along a longitudinal or lateral axis  $x$  of a locomotive 14 or train car at a known distance  $d$  apart. Antenna 10 and antenna 12 feed separate carrier phase GPS receiver 16 and GPS receiver 18, respectively. Receivers 16 and 18 lock on to reference signals from GPS satellites (e.g., 20, 22), and then each receiver 16, 18 performs a carrier phase measurement on a satellite reference signal transmission that it is tracking. This measurement consists of a fractional phase part  $\phi$  and an integer count  $N$  of phase cycles from an initial epoch  $t_0$  to epoch  $t$ .

20 In the following paragraph, a single difference technique is described, although the embodiments described herein can also be applied to a double difference technique. Referring to Figure 1, antenna 10 of receiver 16 is a distance  $d$  away from antenna 12 of receiver 18. Both receivers 16 and 18 receive signals from a satellite, for example 20, at an elevation  $\theta$ , which is essentially identical for both receivers 16 and 18 because of the distance of satellite 20. However, the distance from each receiver 16 and 18 from satellite 20 is different by a measurable amount. Letting  $\phi_1^q$  25 denote a phase measurement made by receiver 16 and  $\phi_2^q$  denote a phase

measurement made by receiver 18 for a  $q$ th satellite (e.g.,  $q=1$  for satellite 20,  $q=2$  for satellite 22), a scaled difference  $\Delta\phi_1^q$  is given by:

$$\Delta\phi^q = (\phi_1^q - \phi_2^q) = \lambda(N_1^q - N_2^q) + c(\Delta t_1^q - \Delta t_2^q) + \vec{\mathbf{d}} \cdot \vec{\mathbf{h}}$$

where  $\Delta\phi^q$  is the single difference for the  $q$ th satellite;

5  $\vec{\mathbf{h}}$  is a unit vector in the direction of satellite  $q$ ,

$\vec{\mathbf{d}}$  is a vector distance between the two antennas 10 and 12,

$N_p^q$  is an integer phase count for the  $p$ th receiver (e.g.,  $p=1$  or 2 for receiver 16 or 18, respectively) and for the  $q$ th satellite;

$\Delta t_p^q$  is an error associated with the  $p$ th receiver for the  $q$ th satellite;

10  $c$  is the speed of light; and

$\lambda$  is a wavelength of the radio signal received from the  $q$ th satellite.

To solve for  $\vec{\mathbf{d}}$ , it is assumed that the clock error and the integer ambiguity between both receivers to the satellites are known. The measurements are made to each of  $n$  satellites in the GPS system, and integer phase counts and clock errors are known or determined. The following are written, where  
 15  $\text{LOS}_x^q, \text{LOS}_y^q$ , and  $\text{LOS}_z^q$  are the  $x, y$ , and  $z$  vector components in the east, north, and up coordinate system of a line of sight to the  $q$ th satellite:

$$\mathbf{H} = \begin{bmatrix} \text{LOS}_x^1 & \text{LOS}_y^1 & \text{LOS}_z^1 \\ \text{LOS}_x^2 & \text{LOS}_y^2 & \text{LOS}_z^2 \\ \vdots & \vdots & \vdots \\ \text{LOS}_x^n & \text{LOS}_y^n & \text{LOS}_z^n \end{bmatrix}$$

$$\vec{y} = \begin{bmatrix} \Delta\phi^1 - \lambda(N_1^1 - N_2^1) - c(dt_1 - dt_2) \\ \Delta\phi^2 - \lambda(N_1^2 - N_2^2) - c(dt_1 - dt_2) \\ \vdots \\ \Delta\phi^n - \lambda(N_1^n - N_2^n) - c(dt_1 - dt_2) \end{bmatrix}$$

$$\vec{d} = \begin{bmatrix} d_x \\ d_y \\ d_z \end{bmatrix}$$

Vector  $\vec{d}$  is a vector representing a baseline in an  $x$ ,  $y$ , and  $z$  coordinate system, representing east, north, and up, respectively. Using the above equations, the following is also written:

$$\vec{y} = \mathbf{H} \vec{d}$$

A solution to the above equation is written:

$$\vec{d} = (\mathbf{H}^T \mathbf{H})^{-1} \mathbf{H}^T \vec{y}, \text{ subject to the additional condition that:}$$

$$\|\vec{d}\| = \text{a distance between antennas 10 and 12.}$$

In another aspect of the present invention, double differencing, as known to those skilled in the art, is used to eliminate clock errors of receivers 16 and 18.

Locomotive 14 rides on a track having limited pitch. Maximum pitches range up to about 2 to 3 percent. Therefore, it is much easier to apply the

constraint on  $\|\vec{d}\|$  and to solve for integer ambiguities of  $N_p^q$  than in more general cases. Once  $\vec{d}$  is determined, an attitude of locomotive 14 is determined at every epoch. By computing differences in the attitude, the attitude rate is computed. Clock errors and integer ambiguities are readily computed, so that a continuous

measurement of heading and heading rate is output from GPS receivers 16 and 18. In particular, heading is given by  $\tan^{-1} \frac{d_x}{d_y}$ , and pitch is given by  $\frac{\tan^{-1} d_z}{\sqrt{d_x^2 + d_y^2}}$ . Thus, a

continuously updated attitude and attitude rate are available. It is only necessary that receivers 16 and 18 maintain phase lock with received signals from the GPS satellites 20, 22... up to an  $n$ th satellite. If phase lock is not maintained cycle slip will occur at which time integer ambiguities will have to be recalculated. Microprocessor 24 coupled to receivers 16 and 18 is used, in one embodiment, to compute at least one of an accurate heading and heading rate. As used herein, microprocessor 24 refers to controllers and processors, including microcontrollers, programmable logic controllers, input/output controllers, reduced instruction set circuits, application specific integrated circuits, logic circuits, and any other circuit, processor or microcomputer capable of processing the embodiments described herein. For example, results are displayed on display 26 or recorded on an internal or external device 28 such as a hard disk or magnetic tape or sent to a navigational computer. In one embodiment, device 28 is a transmitter configured to relay computed location and/or motion information to another location.

A present absolute position of locomotive 14 measured in latitude and longitude is provided by GPS receivers 16 and 18. To resolve an initial integer ambiguity, determine clock offsets, or both, a database 30 is consulted to provide initial heading and grade of a track as a function of the latitude and longitude information. Given LOS values, three unknown parameters  $d_x$ ,  $d_y$ , and  $d_z$  are directly obtained by computation subject to the constraint that a magnitude of  $\vec{d}$  is equal to a distance between antennas 10 and 12.

In yet another embodiment and referring to Figure 2, track database 30 contains measured or otherwise known track curvatures, indexed by location. A single GPS receiver and antenna, for example GPS receiver 16 and antenna 12, provides a position signal 54 (in addition to any other signals provided for other purposes). Using a location inferred from position signal 54, track database 30 is consulted to determine track curvature  $C$  at that location.



Another aspect of the invention is detection of curves and reduction of track wear. Referring to Figures 3 and 4, when wheels 32 of locomotive 14 move over curve 34 on a track 36, resulting friction causes track 36 to wear down. A track is worn down, for example, when a crown (not shown) has worn off. By detecting  
 5 curve 34 and dispensing a lubricant 38 to rails of track 36 while locomotive 14 negotiates curve 34, wear of track 36 rails is reduced. The lubricant 38 may be dispensed from a lubricating system or any system for lubricating the rails of track 36, including lubricant dispenser 44.

Referring to Figure 5, curves 34 are detected in one embodiment by  
 10 utilizing a gyroscope 40 to detect an angular rotation rate  $\omega$  and a tachometer 42 to detect a train velocity  $v$ . Curvature  $C$  is then written  $C=\omega/v$ . One or more lubricant dispensers 44 are configured to dispense lubricant 38 to track 36 rails. Specifically, lubricant dispensers 44 are operated by a microprocessor 24, for example, the microprocessor 24 of Figure 2. Microprocessor 24 is responsive to an angular change  
 15 signal 46 related to  $\omega$  and a tachometer signal 48 related to velocity  $v$  to operate lubricant dispenser 44 to dispense lubricant 38 to track 36 rails when a predetermined magnitude of curvature  $C$  is exceeded.

In another embodiment and referring to Figure 6, an angular change signal (not shown) is determined by microprocessor 24 utilizing signals supplied from  
 20 a pair of GPS receivers 16 and 18 (such as those also shown in Figure 2) from signals received at antennas 10 and 12, respectively. This angular change signal is easily obtained because one attribute of attitude is a heading  $h$ , and  $\Delta h/\Delta t=\omega$ . Tachometer 42 supplies a tachometer signal 48 in this embodiment, and microprocessor 24 computes  $C=\omega/v$ .

In yet another embodiment and referring to Figure 7, a lateral  
 25 accelerometer 50 produces or generates a lateral acceleration signal  $a$ . Microprocessor 24 is responsive to accelerometer 50, signal 52 and tachometer signal 48 to control lubricant dispensers 44. Lubricant 38 is dispensed when a predetermined magnitude of curvature  $C$ , as determined by a ratio  $a/v^2$ , is exceeded.

Lubricant 38 is applied to reduce friction between wheels 32 and track 36 rails when a magnitude of curvature  $C$  is exceeded by an amount to make track wear a concern. Accordingly, in one embodiment, lubricant dispensers 44 are configured to dispense lubricant 38 to wheels 32 rather than directly on track 36 rails.

5 In embodiments in which measurement accuracy is unacceptably compromised by selective availability (SA), differential GPS (DGPS) is used. (SA results from a time-varying drift that either is, or that can be added deliberately to GPS satellite signals to limit absolute measurement accuracy for commercial and non-military applications.)

10 Using one of receivers 16 or 18 in conjunction with microprocessor 24, another aspect of the present invention provides accurate measurements of distance traveled by the locomotive 14. However, it will be recognized that this aspect of the invention is also applicable to other land-based vehicles, as well. In one embodiment, a distance traveled is accurately determined even in the presence of SA with or  
15 without external DGPS connections. Samples of latitude and longitude from one of the receivers, for example, receiver 16, is sampled frequently enough so that errors in these samples are highly correlated. For example, samples are taken about every second. A distance between the samples is computed as a function of differential latitude and longitude. The difference  $\Delta d$  is written as follows:

20 
$$\Delta d = R[\Delta lat^2 + \cos^2(lat)\Delta long^2]^{1/2}$$

where  $\Delta lat$  is a difference between latitudes of consecutive measurements;

$\Delta long$  is a difference between longitudes of consecutive measurements;

and

25  $R$  is the radius of the earth (about 3,440 nmi).

A total distance traveled is a summation of  $\Delta d$  over successive measurements. This distance measurement is accurate even though absolute latitude

and longitude measurements are subject to large errors, because these errors are highly correlated between consecutive measurements and cancel out when differences are calculated. Even errors resulting from selective availability are readily cancelled by this method.

5                   From the preceding description of various embodiments of the present invention, it is evident that navigational parameters of a locomotive are efficiently and inexpensively measured utilizing two GPS receivers, and track wear is reduced through efficient use of lubricant.

10                   Even though a GPS satellite system is described, any satellite system or network may be utilized, for example, GPS, DGPS, and Glonass.

15                   Although the invention has been described and illustrated in detail, it is to be clearly understood that the same is intended by way of illustration and example only and is not to be taken by way of limitation. Accordingly the spirit and scope of the invention are to be limited only by the terms of the appended claims and their equivalents.

WHAT IS CLAIMED IS:

1. A method for determining at least one of motion and location parameters of a locomotive, said method comprising the steps of:

determining a set of phase differences between satellite reference signals received by satellite receivers; and

5 determining at least one of an accurate heading, heading rate, attitude, and attitude rate of the locomotive using the set of phase differences between the satellite reference signals.

2. A method according to Claim 1 further comprising the step of determining  $\vec{d}$ .

10 3. A method according to Claim 2 further comprising the step of determining  $\vec{d}$  as  $\vec{d} = (\mathbf{H}^T \mathbf{H})^{-1} \mathbf{H}^T \vec{y}$ , where:

$$\mathbf{H} = \begin{bmatrix} \text{LOS}_x^1 & \text{LOS}_y^1 & \text{LOS}_z^1 \\ \text{LOS}_x^2 & \text{LOS}_y^2 & \text{LOS}_z^2 \\ \vdots & \vdots & \vdots \\ \text{LOS}_x^n & \text{LOS}_y^n & \text{LOS}_z^n \end{bmatrix};$$

$$\vec{y} = \begin{bmatrix} \Delta\phi^1 - \lambda(N_1^1 - N_2^1) - c(dt_1 - dt_2) \\ \Delta\phi^2 - \lambda(N_1^2 - N_2^2) - c(dt_1 - dt_2) \\ \vdots \\ \Delta\phi^n - \lambda(N_1^n - N_2^n) - c(dt_1 - dt_2) \end{bmatrix}; \text{ and}$$

$$\vec{d} = \begin{bmatrix} d_x \\ d_y \\ d_z \end{bmatrix}.$$

4. A method according to Claim 3 wherein said step of determining at least one of an accurate heading, heading rate, attitude, and attitude rate of the locomotive further comprises the step of determining an attitude and an attitude rate of a locomotive using  $\vec{d}$ , the heading using  $\tan^{-1} \frac{d_x}{d_y}$ , and heading rate

5 using  $\frac{\tan^{-1} d_z}{\sqrt{d_x^2 + d_y^2}}$ .

5. A method according to Claim 1 further comprising the step of determining a track curvature, C.

6. A method according to Claim 5 wherein determining a track curvature comprises the step of detecting an angular rotation rate  $\omega$  and a velocity  $v$  of the locomotive, wherein  $C = \omega / v$ .

7. A method according to Claim 6 wherein detecting an angular rotation rate  $\omega$  and a velocity  $v$  of the locomotive comprises the step of detecting an angular rotation rate  $\omega$  using a gyroscope and a velocity  $v$  of the locomotive using a tachometer.

8. A method according to Claim 6 wherein detecting an angular rotation rate  $\omega$  and a velocity  $v$  of the locomotive comprises the step of detecting an angular rotation rate  $\omega$  using received satellite signals and velocity  $v$  of the locomotive using a tachometer.

9. A method according to Claim 5 wherein determining a track curvature comprises the step of determining a lateral acceleration  $a$  and a velocity  $v$  of the locomotive, wherein  $C = a / v^2$ .

10. A method according to Claim 5 further comprising the step of controlling dispensing of a track lubricant in accordance with the determined curvature value C.

11. A method according to Claim 10 wherein said step of controlling dispensing of a track lubricant further comprises the step of dispensing the lubricant when  $C$  exceeds a predetermined magnitude.

12. A method according to Claim 1 further comprising the steps of:  
 5 determining a position of the locomotive; and  
 accessing a database of track heading and grade to determine a present track heading and grade at the determined position of the locomotive.

13. A method according to Claim 1 further comprising the steps of:  
 sampling latitude and longitude from the satellite receivers; and  
 10 determining a distance traveled by the locomotive.

14. A method according to Claim 13 wherein said step of sampling latitude and longitude from the satellite receivers further comprises the steps of:

sampling where the distance between the samples is determined as  

$$\Delta d = R[\Delta lat^2 + \cos^2(lat)\Delta long^2]^{1/2}$$

15 where  $\Delta lat$  is a difference between latitudes of consecutive measurements;

$\Delta long$  is a difference between longitudes of consecutive measurements; and

$R$  is the radius of the earth (about 3,440 nmi); and

20 said step of determining a distance traveled by the locomotive further comprises the step of summing  $\Delta d$  over successive measurements.

15. An apparatus for determining at least one of motion and location parameters of a locomotive to detect curves and reduce track wear, said apparatus comprising:

at least two phase-locking satellite receivers configured to reference signals received from a set of satellites; and

a processor configured to determine a set of phase differences between the reference signals received by said satellite receivers and at least one of an accurate heading, heading rate, attitude, and attitude rate of the locomotive using the set of phase differences between the reference signals.

16. An apparatus according to Claim 15 wherein said processor further configured to determine  $\vec{d}$ .

17. An apparatus according to Claim 16 wherein said processor further configured to determine  $\vec{d}$  as  $\vec{d} = (\mathbf{H}^T \mathbf{H})^{-1} \mathbf{H}^T \vec{y}$ , where:

$$\mathbf{H} = \begin{bmatrix} \text{LOS}_x^1 & \text{LOS}_y^1 & \text{LOS}_z^1 \\ \text{LOS}_x^2 & \text{LOS}_y^2 & \text{LOS}_z^2 \\ \vdots & \vdots & \vdots \\ \text{LOS}_x^n & \text{LOS}_y^n & \text{LOS}_z^n \end{bmatrix};$$

$$\vec{y} = \begin{bmatrix} \Delta\phi^1 - \lambda(N_1^1 - N_2^1) - c(dt_1 - dt_2) \\ \Delta\phi^2 - \lambda(N_1^2 - N_2^2) - c(dt_1 - dt_2) \\ \vdots \\ \Delta\phi^n - \lambda(N_1^n - N_2^n) - c(dt_1 - dt_2) \end{bmatrix}; \text{ and}$$

$$\vec{d} = \begin{bmatrix} d_x \\ d_y \\ d_z \end{bmatrix}.$$

18. An apparatus according to Claim 17 wherein said processor further configured to determine an attitude and an attitude rate of the locomotive using  $\vec{d}$ , the heading using  $\tan^{-1} \frac{d_x}{d_y}$ , and the heading rate using  $\frac{\tan^{-1} d_z}{\sqrt{d_x^2 + d_y^2}}$ .

19. An apparatus according to Claim 15 wherein said processor further configured to determine a track curvature,  $C$ .

20. An apparatus according to Claim 19 wherein to determine a track curvature, said processor configured to detect an angular rotation rate  $\omega$  and velocity  $v$  of the locomotive.

21. An apparatus according to Claim 20 wherein to detect an angular rotation rate  $\omega$  and velocity  $v$  of the locomotive, said processor configured detect an angular rotation rate  $\omega$  using received satellite signals and velocity  $v$  of the locomotive using a tachometer.

22. An apparatus according to Claim 20 wherein to detect an angular rotation rate  $\omega$  and velocity  $v$  of the locomotive, said processor configured detect an angular rotation rate  $\omega$  using a gyroscope and velocity  $v$  of the locomotive using a tachometer.

23. An apparatus according to Claim 19 wherein to determine a track curvature, said processor further configured to:

determine a lateral acceleration  $a$  and a velocity  $v$  of the locomotive;  
and

determine track curvature  $C$  as:  $C = a / v^2$ .

24. An apparatus according to Claim 19 further comprising a device for dispensing a lubricant to a track.



25. An apparatus according to Claim 24 wherein said processor further configured to control said device dispensing the lubricant in accordance with the determined curvature value  $C$ .

5 26. An apparatus according to Claim 25 wherein said processor further configured to dispense the lubricant when  $C$  exceeds a predetermined magnitude.

27. An apparatus according to Claim 24 wherein said processor further configured to:

determine a position of the locomotive;

10 access a database of track heading and grade to determine a present track heading and grade at the determined position of the locomotive; and

control said device dispensing lubricant in accordance with a curvature value  $C$  contained within the track database.

15 28. An apparatus according to Claim 15 wherein said processor further configured to:

sample latitude and longitude from the GPS receivers; and

determine a distance traveled by the locomotive.

29. An apparatus according to Claim 28 wherein said processor configured to determine a distance between samples as:

20 
$$\Delta d = R[\Delta lat^2 + \cos^2(lat)\Delta long^2]^{1/2}.$$

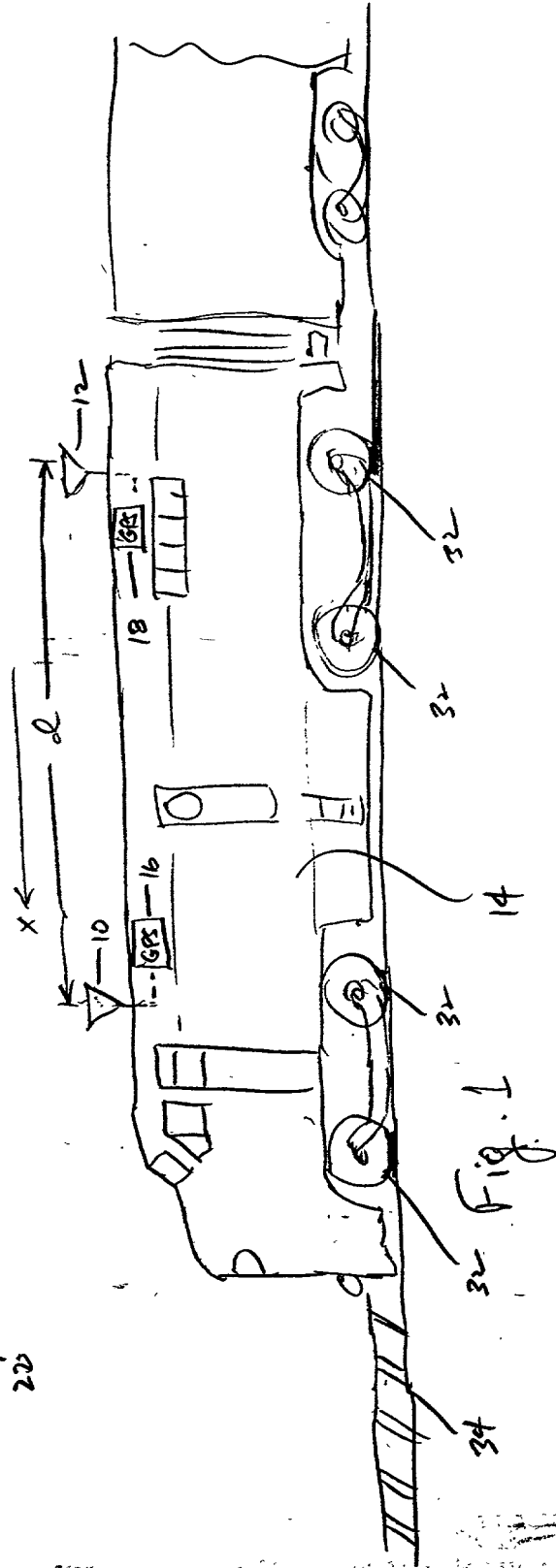
METHODS AND APPARATUS FOR MEASURING  
NAVIGATIONAL PARAMETERS OF A  
LOCOMOTIVE

ABSTRACT OF THE DISCLOSURE

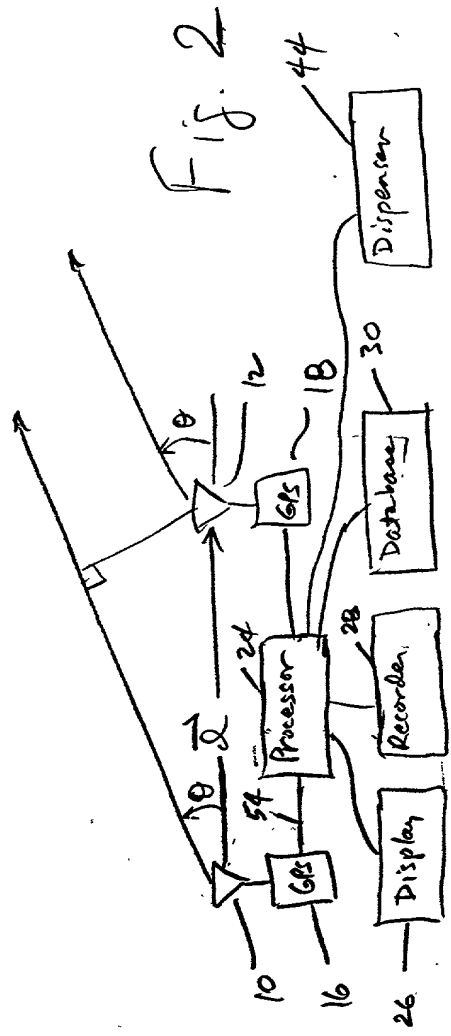
5 The present invention, in one aspect, is a method for determining motion and/or location parameters of a locomotive. One method embodiment includes steps of phase locking a pair of receivers having antennas at different locations on a locomotive to reference signals received from a set of satellites, determining a set of phase differences between the reference signals received at the antennas, and determining at least one of an accurate heading, heading rate, attitude, and attitude rate of the locomotive using the set of phase differences between the reference signals.

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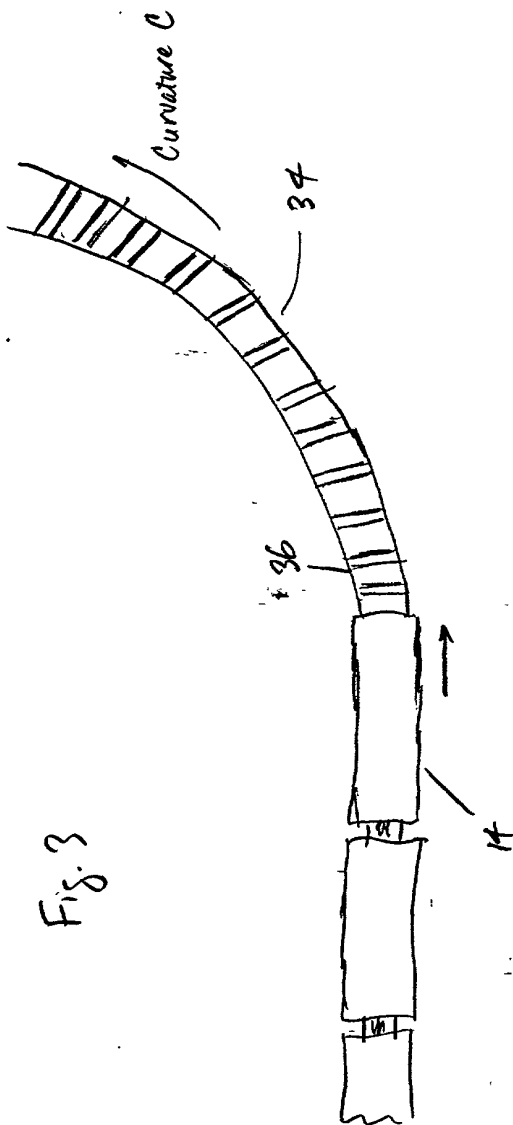


Fig. 3

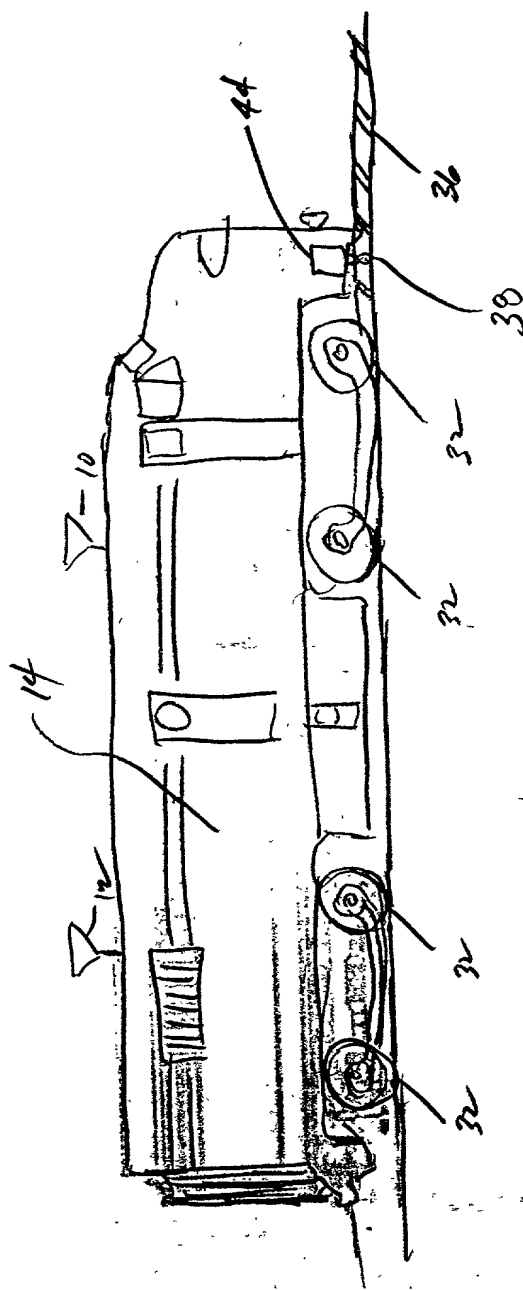


Fig 4

Fig. 5

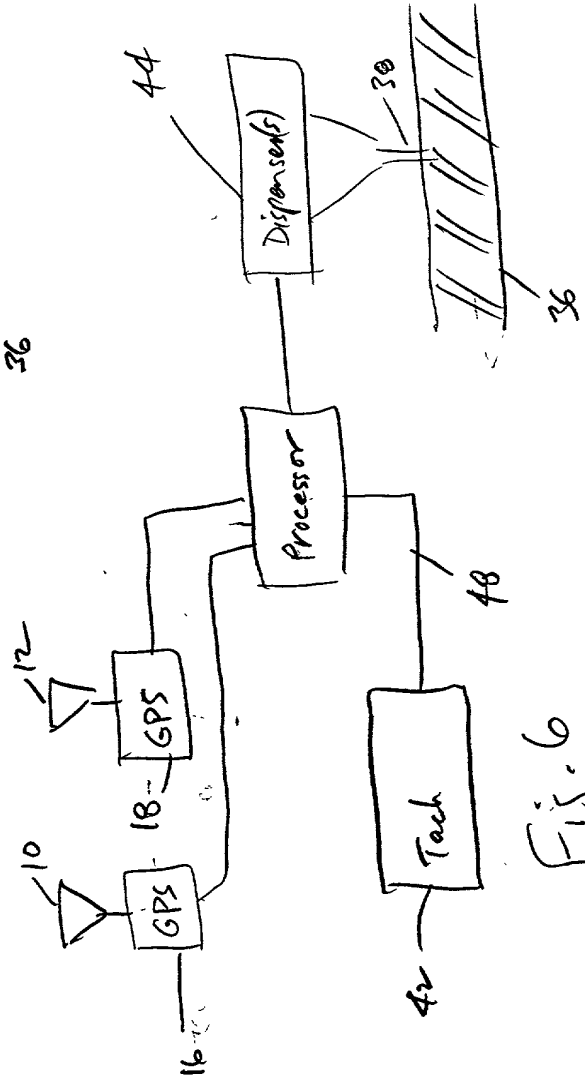
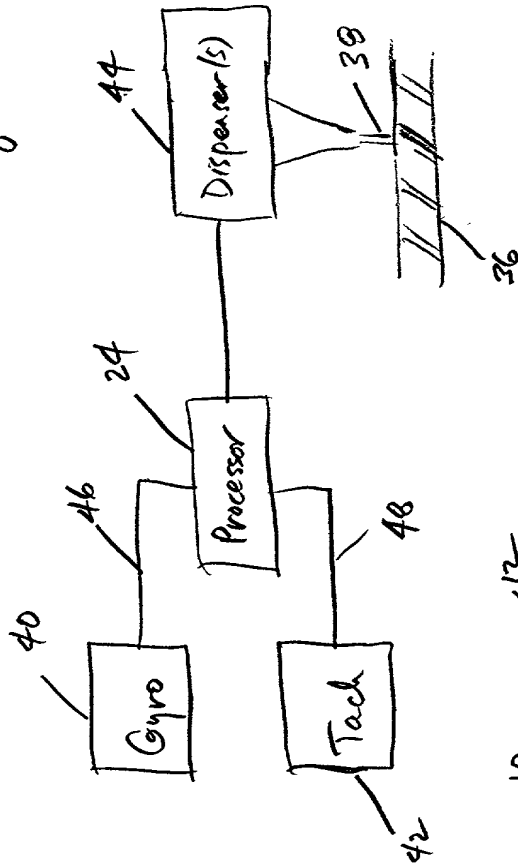
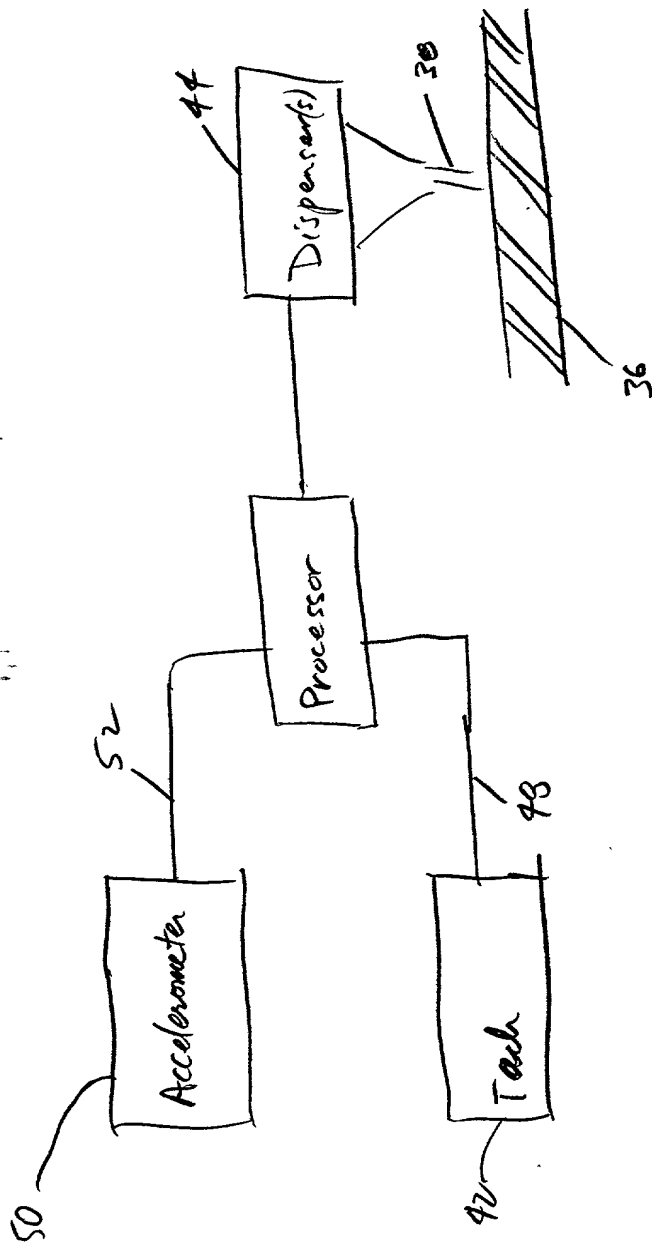


Fig. 6

Fig. 7







**COMBINED DECLARATION AND POWER OF ATTORNEY****Attorney Docket No.****GEH-01-060**

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application and any patent issued thereon.

**SOLE OR FIRST INVENTOR:**Full Name: Charles L. Zahm

Signature: \_\_\_\_\_

Date: \_\_\_\_\_

Residence: Indialantic, Florida 32903Citizenship: U.S.A.Post Office Address: 488 Rio Casa Drive N., Indialantic, Florida 32903**SECOND JOINT INVENTOR, IF ANY:**Full Name: William L. Matheson

Signature: \_\_\_\_\_

Date: \_\_\_\_\_

Residence: Palm Bay, Florida 32905Citizenship: U.S.A.Post Office Address: 1586 Anglers Drive N.E., Palm Bay, Florida 32905**THIRD JOINT INVENTOR, IF ANY:**Full Name: Kevin M. ClyneSignature: 

Date: \_\_\_\_\_

Residence: West Melbourne, Florida 32904Citizenship: U.S.A.Post Office Address: 7903 Timber Lake Drive, West Melbourne, Florida 32904**FOURTH JOINT INVENTOR, IF ANY:**

Full Name: \_\_\_\_\_

Signature: \_\_\_\_\_

Date: \_\_\_\_\_

Residence: \_\_\_\_\_

Citizenship: \_\_\_\_\_

Post Office Address: \_\_\_\_\_

**FIFTH JOINT INVENTOR, IF ANY:**

Full Name: \_\_\_\_\_

Signature: \_\_\_\_\_

Date: \_\_\_\_\_

Residence: \_\_\_\_\_

Citizenship: \_\_\_\_\_

Post Office Address: \_\_\_\_\_

**COMBINED DECLARATION AND POWER OF ATTORNEY****Attorney Docket No.****GEH-01-060**

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled: **METHODS AND APPARATUS FOR MEASURING NAVIGATIONAL PARAMETERS OF A LOCOMOTIVE**, (Docket No. GEH-01-060) the specification of which:

(check one)

☒

is attached hereto

☐

was filed on \_\_\_\_\_ as Application Serial No. \_\_\_\_\_,

and was amended on \_\_\_\_\_.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations §1.56(a).

I hereby claim priority benefits under Title 35, United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §112. I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

Application Serial No.Filing DateStatus (patented, pending, abandoned)

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I hereby claim the benefit under Title 35, United States Code §119(e) of any United States provisional application(s) listed below:

Application Serial No.Filing DateAdditional provisional application  
numbers are listed on a  
supplemental  
priority sheet attached hereto.60/153,30409/10/99

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I hereby appoint Scott R. Hayden, Reg. No. 41,821 of GE-Harris Railway Electronics, L.L.C., P.O. Box 8900, Melbourne, FL 32902; and John S. Beulick, Reg. No. 33,338; Patrick W. Rasche, Reg. No. 37,916; Michael Tersillo, Reg. No. 42,180; Alan L. Cassel, Reg. No. 35,842; Elizabeth D. Odell, Reg. No. 39,532; Bruce T. Atkins, Reg. No. 43,476; and Natu J. Patel, Reg. No. 39,559 of Armstrong Teasdale LLP, One Metropolitan Square, Suite 2600, St. Louis, MO 63102, jointly, and each of them severally, my attorneys and attorney, with full power of substitution, delegation and revocation, to prosecute this application, to make alterations and amendments therein, to receive the patent and to transact all business in the Patent and Trademark Office connected therewith.

I hereby direct that all correspondence and telephone calls in connection with this application be addressed to the said

John S. Beulick, Reg. No. 33,338  
Armstrong Teasdale LLP  
One Metropolitan Square, Suite 2600  
St. Louis, MO 63102.  
Telephone No. (314) 621-5070.

**COMBINED DECLARATION AND POWER OF ATTORNEY****Attorney Docket No.****GEH-01-060**

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application and any patent issued thereon.

**SOLE OR FIRST INVENTOR:**Full Name: Charles L. ZahmSignature: Charles L. ZahmDate: 5/8/00Residence: Indialantic, Florida 32903Citizenship: U.S.A.Post Office Address: 488 Rio Casa Drive N., Indialantic, Florida 32903**SECOND JOINT INVENTOR, IF ANY:**Full Name: William L. MathesonSignature: William L. MathesonDate: 5/8/00Residence: Palm Bay, Florida 32905Citizenship: U.S.A.Post Office Address: 1586 Anglers Drive N.E., Palm Bay, Florida 32905**THIRD JOINT INVENTOR, IF ANY:**Full Name: Kevin M. Clyne

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Date: \_\_\_\_\_

Residence: West Melbourne, Florida 32904Citizenship: U.S.A.Post Office Address: 7903 Timber Lake Drive, West Melbourne, Florida 32904**FOURTH JOINT INVENTOR, IF ANY:**

Full Name: \_\_\_\_\_

Signature: \_\_\_\_\_

Date: \_\_\_\_\_

Residence: \_\_\_\_\_

Citizenship: \_\_\_\_\_

Post Office Address: \_\_\_\_\_

**FIFTH JOINT INVENTOR, IF ANY:**

Full Name: \_\_\_\_\_

Signature: \_\_\_\_\_

Date: \_\_\_\_\_

Residence: \_\_\_\_\_

Citizenship: \_\_\_\_\_

Post Office Address: \_\_\_\_\_